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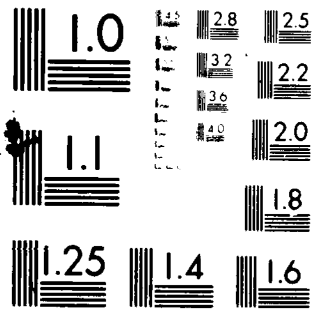

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FEASIBILITY STUDY ON THE CONVERSION
OF AIR FORCE OIL-FIRED HEAT PLANTS
TO COAL-OIL-MIXTURE FIRED PLANTS

Edward J. Pokora, Captain, USAF

LSSR 75-81

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The Air Force is the primary Department of Defense user of petroleum based fuels for the operation of its aircraft, facilities and other support equipment. Alternative energy sources must be explored and utilized to minimize the cost to the Air Force for these fuels. This research explored the feasibility of mixing coal with oil to produce a mixture capable of being burned in existing Air Force boilers. Four technologies were examined by comparing relative Life-Cycle Costs for retrofitting existing boilers and also by means of applying a standardized questionnaire to case studies. This research concluded that of the four current technologies available for mixing coal in oil, the ultrafine coal-oil mixture process would be the best suited for central plant boilers such as those that exist on Air Force installations.

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FEASIBILITY STUDY ON THE CONVERSION OF AIR FORCE OIL-FIRED HEAT PLANTS TO COAL-OIL-MIXTURE FIRED PLANTS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

By

Edward J. Pokora, BSCE
Captain, USAF

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CHAPTER I

INTRODUCTION

Statement of the Problem

The technology to grind coal and mix it with oil or to grind coal in oil has existed for a very long time. The technology to accomplish this mixing has been in development for over one-hundred years. There were several factors hindering the full development of coal-oil-mixtures. Among these was the low cost of oil, especially in the United States, OPEC price setting and, finally, difficulties in creating a stable mix. Over time the coal in oil would go out of suspension in the mix, making storage of the mixture difficult (17:21).

Now since the 1973 Arab Oil Embargo, the price of oil has increased to the point where alternative sources of energy must be utilized. This increase in the price of Middle East oil has caused a greater dependence on domestic reserves. By mixing coal in oil and using this mixture as the primary fuel in our boilers, less domestic oil as well as imported oil will be needed to be used for operation of boilers (16:4).

The conversion to coal-oil-mixtures costs less than converting existing boiler plants to ones using coal only.

Also the construction of a coal-oil-mixture boiler plant costs less to build and operate than other synfuel plants (6:2). Coal-oil-mixture plants also enhance environmental performance compared to direct coal firing (10:2).

The Department of Defense is the single largest consumer of oil for the purpose of running numerous boiler plants in the United States and overseas. The Air Force is the largest of the components of the DOD and a need exists for the Air Force to review the coal-oil-mixture alternative. The Air Force needs to determine what problems or issues currently confront energy managers and to determine if the conversion of conventional oil-fired boilers to coal-oil-mixture fired plants is a feasible alternative.

Background and Justification

Managerial planning for a major conversion such as the conversion of existing oil-fired plants to coal-oil-mixture fired plants is a continuing process not limited to static, one-time projections of costs and assessments of technical risks (3:4).

On 14 November 1979 the Department of Energy submitted a program opportunity notice inviting commercial companies to propose boiler retrofit programs that employ coal-oil-mixture technologies. In the DOE program opportunity notice it was stated that: "The combustion of coal in

liquid phase suspensions is one of the few near-term technologies available to help alleviate our nation's energy problems [17:3]."

Modification Technologies

A variety of techniques have been developed for the manufacture of coal-oil-mixtures. There are basically four general approaches used in the United States today. They are: ultrafine grinding, ultrasonics, dry grinding/chemical stabilization and finally wet grinding/chemical stabilization (2:4). These approaches differ primarily in the method of coal grinding and in the method of stabilizing the coal-oil-mixture. Table 1 shows the status of the various technologies (13:2).

British Petroleum (BP) and COMCO, a partnership formed by the Florida Power Corporation and the Dravo Corporation, grind the coal much finer than other coal-oil-mixture developers, relying on the small size of the coal particles rather than any additives to yield a stable coal-oil-mixture. CoaLiquid, another developer, and its licensees use an approach patented by Eric Cottell. The coal is ground conventionally so that 80 percent passes a number 200 mesh screen. A stable coal-oil-mixture is obtained by the addition of water and by later ultrasonic processing. General Motors, and the New England Power Service Company (NEPSCO) have used more conventional

TABLE 1

STATUS OF ALTERNATIVE COM PREPARATION TECHNOLOGIES [13:4]

Process	Method of Grinding	Method of Stabilization	Developer	Plant Size (bpd)	Start-up
Ultrafine Grinding	Fluid Mill, 50%-15μ	No Additive	COMCO	3000	1981
	Attritor, 50%-15μ	No Additive	BP	1449	1981
Ultrasonic	Dry Grinding, 80%-75μ	Water & Ultrasonics	CoaLiquid	1190	1979
	Dry Grinding, 80%-75μ	Water & Ultrasonics	Banklick	6000	1981
Dry Grinding/ Chemical Stabilization	Dry Grinding, 80%-75μ	SAA	GM	600	1978
	Dry Grinding, 80%-75μ	SAA		2278	1980
Wet Grinding/ Chemical Stabilization	Wet Grinding Coal in Oil, 80%-75μ	SAA	EPDC	-	1980

mixing equipment to disperse and blend the components of their coal-oil mixtures. In the GM and NEPSCO processes, the stability of the coal-oil-mixture is enhanced by the addition of various surface-active agents, sometimes using a water solution. The GM/NEPSCO method of stabilization is referred to as dry grinding/chemical stabilization. In Japan, the Electric Power Development Company (EPDC) is also developing a chemically stabilized coal-oil-mixture, but it employs wet grinding methods to obtain a coal powder and to mix the coal and oil initially. The EPDC method is referred to as the wet grinding/chemical stabilization process (13:1-2).

There are some other second generation coal-oil-mixture technologies which incorporate chemical modification of the coal. These technologies are currently under development by the Gulf and Western, and Rolfite Companies (11:1). These technologies have not yet reached the same level of development as the other four technologies mentioned (13:2). Literature is not available and preliminary combustion test results have not yet been published on these technologies.

Limitation

The four coal-oil-mixture technologies listed in Table 1 will be the primary focus of this thesis effort. The technologies will be compared by use of case studies

and other literature written on the subject of coal-oil-mixtures. A standardized questionnaire will be used to analyze each case study on the same standards.

The advanced technologies mentioned in modification technologies will not be discussed in this thesis.

As a specific test of a plant for the purposes of this thesis was not performed, comparisons will be drawn for application to Air Force boilers for boiler number 3 at Dover Air Force Base, Delaware.

Literature Review

Information on current technologies concerning coil-oil-mixtures came from several sources. Official regulations, the popular press, academic research, and the people who are employed in the area of interest are all valuable resources.

The initial search for information was based on the following resources:

1. A review of the Reader's Guide to Periodic Literature, and U.S. Department of Defense Bibliography of Logistics Studies and Related Documents.

2. A search for previous studies, projects, and theses by subject (coal-oil mixtures) from the Defense Documentation Center (DDC) and the Defense Logistics Studies Information Exchange (DLSIE).

3. Information and reports contained in the Second and the Third International Symposium on Coal-Oil Mixture Combustion.

4. Various manufacturer data and test reports from civilian industry such as CoaLiquid, Inc. were incopo-rated into this thesis.

One article in particular from The Military Engineer, March-April 1981, enabled the further collection of information and contact of knowledgeable sources on coal-oil mixtures. This article was entitled "Stretching Petroleum Supplies" and was written by Mr. George Fumich, Jr., the first Assistant Secretary for Fossil Energy. His article was an overview of the entire coal-oil mixture situation and did not cover any specifics on the subject. Upon contacting the Department of Energy it was learned that under the new Republican administration, the fossil energy Department was to have its staff cut in half. The Reagan administration believes civilian industry should explore avenues for better use of fossil energy. If there is a profit to be made industry will pursue it (7:114). This led to contacting Mr. David C. Fuller of CoaLiquid, Inc., a company specializing in the same and manufacture of small scale coal-oil mixture retrofits. Numerous case studies and test data were received from this company as well as general literature on the subject of COMs. Some of the case

histories received from this company will be discussed later in this thesis.

The next major source of literature and data on the subject of coal-oil mixtures was contained in the proceedings of the Second International Symposium on Coal-Oil Mixture Combustion held in November 1979 in Danvers, Massachusetts. In the proceedings of this symposium overviews of the U.S. DOE coal-oil mixture program, overview of the R&D status of COM technology in Japan, the current status of the Canadian coal-oil mixture program, and numerous other COM programs being conducted throughout the world were discussed in great detail. Reports of special interest to the DOD and in particular the Air Force will be analyzed in detail later in this thesis.

Other sources of information were from magazine periodicals which were in general overviews on the subject giving the status of COM technology.

Objectives

The objectives of the proposed research are:

1. Select the most appropriate coal-oil mixture technology for Air Force application based on presently available methods.

2. Determine the total Life-Cycle Cost of the currently available coal-oil mixture technologies to be used in conjunction with the results of objective number 1

to select which one of the coal-oil mixture processes would be the most appropriate for United States Air Force application on the basis of both performance and minimum total Life-Cycle Cost.

Research Questions

The answers to the following research questions will provide the means to fulfill the research objectives:

1. Which one of the four current coal-oil mixture technologies would be the most feasible for USAF use according to data contained in case studies?

2. Of the four current coal-oil mixture technologies available, which one on the basis of minimum Life-Cycle Cost would be most appropriate for United States Air Force application?

CHAPTER II

METHODOLOGY

Scope

This research effort analyzed coal-oil mixture technologies by applying both economic analyses and a subjective questionnaire.

The population for this study consisted of all available case studies on the subject of coal-oil mixtures published in years 1979 through 1981. This time frame was chosen because, although coal-oil mixture concepts have been available for over 100 years, new technologies that are cost effective and meet environmental pollution standards have only been developed in the last two or three years (14:4). The 1973 Arab Oil Embargo was the primary reason such emphasis was placed on new coal-oil mixture technologies (14:1).

The economic analysis of coal-oil mixtures was performed on the basis of Total Life Cycle Costs in accordance with the second research question. Manufacturer cost data dated 1979 were the primary source of inputs to the Life Cycle Cost analysis. These cost data were the most current information available to the researcher.

Data Collection

The data source which enabled the further collection of case studies on the subject of coal-oil mixtures and manufacturer cost figures on coal-oil mixture technologies was an article entitled "Stretching Petroleum Supplies," contained in the March-April issue of The Military Engineer. This article was written by Mr. George Fumich, Jr., Assistant Secretary for the Department of Energy's Fossil Energy branch (10:113). Upon contacting the fossil energy branch of the DOE, referrals were given to the Pittsburg Energy Technology Center and CoaLiquid, Inc., both of whom contributed the bulk of the data for this thesis effort.

Other sources of data were papers presented at the Second International Symposium on Coal-Oil Mixture Combustion held on 27 November 1979, at Danvers, Massachusetts. Another source of data for this thesis was previous research done on the subject contained in papers obtained through the Defense Technical Information Center (DTIC).

Analysis of Data

Research Question Number 1

Data for the first research question consisted of case studies on each of the four coal-oil mixture technologies being examined.

A standard questionnaire consisting of twelve questions was developed to subjectively analyze the case studies. These questions were structured so as to address the major areas of concern in a coal-oil mixture retrofit as identified in interviews with engineers actively involved in application of these technologies (4; 9).

Case studies were chosen for each of the four coal-oil mixture technologies being analyzed. Factors used in determining which cases to use were: (1) the case study was performed on a boiler of capacity of 1100 mmbtuh or a pilot plant with the intention of later application to a boiler of this capacity, and (2) the case study was complete in regards to questions contained in the standard questionnaire.

The questions contained in the questionnaire were applied to each of the cases selected for analysis. Each of the questions was given a rating of from one to five indicating that the boiler plant using the given stabilization process did or did not meet the requirements of the question. A key to the ratings employed in the analysis of the cases is contained in Appendix B. Upon rating the cases in each of the twelve areas, the ratings were totalled and the case received an overall composite score between 12 and 60. This composite score enabled the placement of a particular coal-oil mixture technology in relative standing with the other three technologies.

Research Question Number 2

Data for the second research question consisted of cost data obtained from CoaLiquid, Inc., a manufacturer of coal-oil mixture retrofit equipment and from an economic report titled "Coal-Oil Mixture Economics September 1979" written by G. A. Christie of the Davy McKee Corporation (3:12-20).

There are several different ways of combining the data on cost and savings from a project to evaluate its economic performance. The mode of analysis chosen in analyzing the four coal-oil mixture technologies is the Total Life-Cycle Costs (TLCC) approach (5:24). This approach takes all relevant values over the entire study period, which was twenty-five years, and discounts them to a common time basis (5:25).

The general formula used in the Total Life-Cycle Cost analysis is:

TOTAL LIFE-CYCLE COST		INVESTMENT COSTS		SALVAGE VALUE		NONFUEL O&M COSTS		REPLACEMENT COSTS		ENERGY COSTS
TLCC	=	I	-	S	+	N	+	R	+	E

where all amounts are expressed as present values (5:25).

In analyzing the inputs to the Total Life-Cycle Costs equation, all future amounts were expressed in constant dollars with the base year being 1979-1980. Costs dated 1979 were not inflated to 1980 values but were employed in the analysis as given by the data source.

In estimating the quantity of energy, a boiler of sufficient capacity to consume 5,000 barrels of oil per day (1100 mmbtuh) was chosen as cost data were supplied by CoaLiquid, Inc. for this size of plant. Energy figures used were obtained by telephone interview from David C. Fuller, Vice President, Marketing, CoaLiquid, Inc. and from a paper obtained from G. T. Hawkins, an engineer with CoaLiquid, Inc. (12:26).

Base year energy prices were converted to mid 1980 dollars and were based on the U.S. average, DOE base-year energy prices. Future energy prices were estimated using DOE projected energy price escalation rates. Consistent with OMB Circular A-94, a discount rate of 7 percent, not including inflation, is used to obtain the present value equivalents of future cash amounts (5:39). Investment costs were treated as a lump-sum present value amount occurring at the beginning of the base year and constituted 90 percent of actual investment costs (5:34). Annually recurring nonfuel operations and maintenance costs considered in the analysis represented the differences in personnel costs among the six options. Nonannually recurring repair, replacement costs and salvage values were assumed to occur as a lump sum at the end of the year in which they are estimated to occur. From interviews with CoaLiquid, Inc. for a twenty-five year life, these costs could be assumed to occur at five-year intervals with no cost to be incurred

at the end of twenty-five years. Salvage costs were assumed to be identical for each of the options, therefore this cost was omitted from the analysis.

Assumptions

1. Each case study contained sufficient information to enable the researcher to extract accurate responses for the questionnaire.

2. Data for the Total Life-Cycle Cost calculations are accurate as supplied by both a manufacturer of coal-oil mixture retrofit equipment and a technical report from an engineering consulting firm.

3. Relative standings of the four coal-oil mixture technologies based on Total Life-Cycle Cost combined with the standings developed from the application of the standard questionnaire would enable the researcher to appropriately rank the technologies with the limited data available.

Limitations

1. Due to limited data on the subject of coal-oil mixtures, cost data from only two sources will be employed in the Total Life-Cycle Cost analysis and therefore may inhibit the validity of the results.

2. Responses for the questionnaire were derived from one case on each of the four coal-oil mixture

technologies. Basing the subjective analysis for each technology on one case may inhibit the validity of the results.

CHAPTER III

PRESENTATION OF THE RESULTS

Introduction

Review of the cases selected for analysis appears to support the contention among commercial industry that out of the four current coal-oil mixture technologies available, the ultrasonic stabilization method is the most viable without regard to cost (15:3).

This contention is further supported by the Total Life-Cycle Cost analysis which also indicated that the ultrasonic stabilization method had the lowest Total Life-Cycle cost of the four currently available coal-oil mixture technologies.

The analysis to follow will review the data from each question obtained through application of the standard questionnaire (see Appendix B) and identify why each case received the rating that was assigned by the researcher.

Presentation of the Data

Research Question Number 1

Question Number 1. All four coal-oil mixture technologies received a rating of 4 in that they were all effective in meeting the goals of the specific case. A few of the cases indicated minor difficulties in the retrofit

which will be addressed in later questions contained in the questionnaire. None of the cases received a rating of 5 in this area because each had its own peculiar difficulties in varying degrees.

Question Number 2. Of the technologies examined, the ultrasonic (Cottell) process was the easiest to introduce as a retrofit project. By performing the following modifications, the ultrasonic (Cottell) process was superior to the other three technologies: (1) modification of the burner by introducing wear resistant alloys and enlarged orifices, and (2) increasing the capacity of fuel pumps in the fuel train and installation of stack collectors to control flyash (20:15). Although the overall advantages the ultrasonic process has over the other technologies is slight in regards to this question, the researcher believed the ultrasonic process was effective while the other technologies were only marginally effective. Therefore, the ultrasonic process received a rating of 4 while the others were judged to be approximately equal in regards to this question, receiving a rating of 3.

Question Number 3. Of the four technologies, all were effective except the ultrafine stabilization process in regards to the settlement rates of the coal-oil mixture. The most significant data on ultrafine coal-oil mixtures has been reported by British Petroleum

and Tufts University which were in agreement with the results of this thesis (22:5). In particular, the phase separation properties of the ultrafine stabililization method are not effective in regard to storage, pumping and at high temperatures (2:14). The researcher assigned a rating of 2 (slightly ineffective) for the ultrafine process, while the other technologies received marginally effective ratings with the ultrasonic method being judged the most stable, receiving a rating of 4 (effective).

<u>Question Number 4</u>. The ultrafine stabilization process has the highest combustion efficiency of the four technologies, although all technologies were effective in this area. The ultrafine coal-oil mixture is a 50/50 blend of coal and oil while the ultrasonic is a 45/45/10 blend of coal, oil and water. The two chemically stabilized methods also incorporated water but used a chemical additive to keep the coal particles in suspension. The ultrafine process uses all combustible products while the other technologies did not, resulting in lower combustion efficiencies. The ultrafine process received a rating of 5 while the other technologies received a rating of 4 in regards to safety for plant personnel due to lower temperatures employed.

<u>Question Number 5</u>. As discussed in the analysis for question number 4, the ultrafine stabilization process

has the highest efficiency rating. The more water that is present in the coal-oil mixture, the lower the coal-oil mixture heating value will be. Since the ultrafine coal-oil mixture does not employ water it will have the highest heating value. The differences in heating value between the four technologies is slight (between 29.84 and 26.64 mmbtu/ton) and is the primary reason the researcher assigned an effective rating of 4 to all the technologies (17:6).

Question Number 6. All four technologies were effective in regards to using little energy to produce the coal-oil mixture. The chemical additive/wet grinding method required the most energy to produce the mix. The chemical additive/ wet grinding method received a rating of 4 while the other three technologies received extremely effective ratings of 5.

Question Number 7. Out of the four technologies, only two of the methods employed chemicals as a stabilizer. Escape of carcinogens to the outside environment is almost totally eliminated by the stack collector. Since two technologies did not employ chemicals at all, they received a 5 rating, while the other technologies that did employ chemical stabilization received ratings of 4.

Question Number 8. As discussed in questions 3 and 4, time is most critical in the ultrafine method of

stabilization. All the stabilization methods require some type of mechanical restabilization before being burned, but the ultrafine method requires mechanical stabilization the most. The ultrafine method received a rating of 1 in this area (ineffective), while the other three methods were judged by the researcher to be only marginally effective, receiving a rating of 3.

<u>Question Number 9</u>. Equipment for all four technologies is approximately the same except for the technologies employing chemical additives. Precise metering equipment is required to minimize potential antagonistic effects between the deliberately added stabilizer and other surface active compounds which might already be present in the fuel oil (17:8). Product quality is the main area of concern for all the technologies. The ultrafine and ultrasonic technologies met the requirements of this question and received an effective rating of 4, while the two chemically stabilized methods were assigned a marginally effective rating of 3.

<u>Question Number 10</u>. The addition of water to the coil-oil mixture generally worked well in all the technologies employing it except for the chemical additive/ dry grinding method. The role of the water in the mix was to: (1) improve the fuel efficiency of the mix by causing micro-explosions which results in finer coal particles and

more complete combustion, (2) controlling dust at the stockpile as the coal can be wetted, (3) reducing the possibility of coal dust explosions, (4) controlling the flame temperature of the boiler resulting in less SO_x and NO_x being given off to the atmosphere, and (5) the water permits more complete combustion, resulting in fewer unburned hydrocarbons. In the chemical additive/dry grinding method of stabilization, temperatures above 100°C are used, causing the water to boil and later turn into steam. In the ultrafine process where temperatures of the mix are kept low until introduction into the boiler, the water performed its five primary functions in the coal-oil mixture extremely well. This fact enabled the researcher to assign a rating of 5 (extremely effective) for this technology. In the ultrasonic and chemical additive/ wet grinding methods the water performed its five major functions enabling the researcher to assign these technologies an effective rating of 4. Due to the high temperatures used in the chemical additive/dry grinding technology, the water proved to inhibit the proper functioning of the system. The researcher assigned this technology a marginally effective rating of 3.

Question Number 11. At the present time coal-oil mixtures do not meet air pollution standards unless expensive baghouses and particle removers are employed in the

process. All the cases received a rating of 3 (marginally effective) in this area.

Question Number 12. In every case the coal-oil mixture can be utilized as a marine diesel fuel with minor modifications. Technologies utilizing relatively large amounts of water and chemical additives will require modifications to the marine diesel engine itself. All the technologies received a rating of 4 (effective) in this area.

A summary of the twelve questions is contained in Table 2.

Research Question Number 2

This research question was answered using a Life-Cycle Cost approach. The method used to determine the relative standings of the six options analyzed was Total Life-Cycle Cost as outlined in the Life Cycle Costing Manual for the Federal Energy Management Programs (5: Chap. 4). Forms for the calculation of the Total Life-Cycle Cost for each of the six options are contained in Appendix C. The results of the Total Life-Cycle Cost calculations are shown in Table 3.

The results of the Total Life-Cycle Cost analysis selected the ultrasonic stabilization method over the other technologies. The main differences noted in the Total Life-Cycle Cost analysis between the technologies was in the fuel cost and nonannually recurring maintenance costs

TABLE 2

QUESTIONNAIRE SURVEY RESULTS

Case	Process	Questions from Questionnaire												
		1	2	3	4	5	6	7	8	9	10	11	12	Total
1	Ultrafine	4	3	2	5	4	5	5	1	4	5	3	4	45
2	Ultrasonic (Cottell)	4	4	4	4	4	5	5	3	4	4	3	4	48
3	Chemical Additive Dry Grinding	4	3	3	4	4	5	4	3	3	4	3	4	44
4	Chemical Additive Wet Grinding	4	3	3	4	4	4	4	3	3	3	3	4	42

Note: See Appendix B for key to ratings.

TABLE 3

SUMMARY OF LIFE-CYCLE COST CALCULATIONS

Option	Description	TLCC	SIR[a]	Rank
1	Oil fired plant	$\$1,149.6 \times 10^6$	-	6
2	Oil fired to coal fired	$\$\ 257.9 \times 10^6$	29.4	1
3	Ultrafine grinding	$\$\ 714.5 \times 10^6$	18.6	3
4	Ultrasonic	$\$\ 687.5 \times 10^6$	21.6	2
5	Chemically stabilized dry grinding	$\$\ 725.0 \times 10^6$	16.7	4
6	Chemically stabilized wet grinding	$\$\ 734.1 \times 10^6$	15.8	5

Note: "Selecting projects in descending order of their SIR's . . . can be expected to result in a larger return per investment dollar and, hence, a greater total dollar savings for a given budget than selecting projects according to their TLCC, their NS, or their PB [5:34]."

[a]SIR = Savings to Investment Ratio.

as indicated in Appendix C. The nonannually recurring maintenance costs varied from $25,000 for five-year increments over the twenty-five year life for the ultrasonic process to $60,000 at five-year increments for the two chemical additive methods of stabilization.

Analysis of the Data

Combination of the Results of the Case Review and Total Life-Cycle Cost Calculations.

Although the answers to the two research questions both identified the ultrasonic coal-oil mixture technology as being superior to the others on the basis of subjective variables and Total Life-Cycle Cost, there was a disparity in the relative standings of the other options. The results of the two methodologies of analysis are summarized in Table 4.

Both methodologies as previously indicated, selected the ultrasonic method of stabilization as being superior to the others in the study. Disparity exists in the ranking of the other technologies in the study, although the variation is slight.

The results indicate that the least desirable retrofit technology would be the chemical additive/wet grinding method due to its high Total Life-Cycle Cost and its inherent problems outlined in the subjective questionnaire.

TABLE 4

COMBINATION OF RESULTS

		Questionnaire Results		TLCC Results		
Option	Description	Composite Score	Rank	TLCC	SIR	Rank
1	Existing No. 6 Fuel-oil Boiler plant	*	-	$1,149.6 x 10^6	-	-
2.	Retrofit from oil fired to coal fired	*	-	$ 257.9 x 10^6	29.4	-
3.	Retrofit from oil fired to ultrafine grinding COM	45	3	$ 714.5 x 10^6	18.6	2
4.	Retrofit from oil fired to ultrasonic COM	48	1	$ 687.5 x 10^6	21.6	1
5.	Retrofit from oil fired to chemical additive/dry grinding COM	44	2	$ 725.0 x 10^6	16.7	3
6.	Retrofit from oil fired to chemical additive/wet grind COM	42	4	$ 734.1 x 10^6	15.8	4

*Note: Standardized questionnaire was not applied to the existing oil-fired plant nor to conversion to a 100 percent coal-fired plant.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Summary

The development of alternate energy sources as a substitute for petroleum is becoming one of the primary goals of the United States Government and also of the commercial sector of the economy (1:26). Of all the current technologies such as solar energy, wind power and coal degasification, only the coal-oil mixture option offers a direct substitute for oil and is near-term technology (8:2).

This thesis effort analyzed the four current technologies available to retrofit existing No. 6 fuel oil fired boiler plants to plants capable of using coal-oil mixtures. The four technologies examined were: (1) the ultrafine grinding stabilization method, (2) the ultrasonic stabilization method, (3) the chemically stabilized dry grinding stabilization method, and (4) the chemically stabilized/wet grinding stabilization method. The overall objective of this thesis was to select which one of the technologies would be the most practical for application to existing oil-fired Air Force boilers.

In order to solve this problem, two objectives were established. The first objective was to select the

most appropriate coal-oil mixture technology for Air Force application based on presently available methods. The second objective was to determine the Total Life-Cycle Cost of the currently available coal-oil mixture technologies to be used in conjunction with the results of objective number 1 in selecting which one of the coal-oil mixture processes would be most appropriate for USAF application. The first objective was met by applying a standard questionnaire to case studies on each of the four coal-oil mixture technologies. Rank scoring values in twelve areas were summed, the technology was assigned a composite score and the composite values were put in rank order placing the technologies in relative standing with each other.

The second objective was met by performing a Total Life-Cycle Cost analysis for each of the four technologies in comparison to an existing No. 6 fuel-oil fired boiler of capacity to burn 5,000 barrels per day (approximately 1100 mmbtuh). Each technology was placed in relative standing on the basis of its Total Life-Cycle Cost.

Conclusions

The analysis of the above data provided the information needed to answer the two basic research questions:

1. Which of the four current coal-oil mixture technologies would be the most feasible for USAF use according to data contained in case studies?

2. Of the four current coal-oil mixture technologies available, which one on the basis of minimum Life-Cycle Cost would be most appropriate for United States Air Force application?

Research Question Number 1

Based on the analysis of case studies with a standard questionnaire, the relative ranking of the coal-oil mixture technologies is as follows with the ultrasonic stabilization method being determined as the most desirable (Table 5).

TABLE 5

CASE STUDY RANKING

Rank	Technology
1	Ultrasonic Stabilization
2	Chemical Additive/Dry Grinding
3	Ultrafine Grinding
4	Chemical Additive/Wet Grinding

Research Question Number 2

The results of the Total Life-Cycle Cost calculations are shown in Table 6.

In both methods of analysis, the ultrasonic stabilization method was selected as the superior technology. The standard questionnaire assigned the ultrasonic

TABLE 6

TLCC RANKING

Rank	Technology
1	Ultrasonic Stabilization
2	Ultrafine Grinding
3	Chemical Additive/Dry Grinding
4	Chemical Additive/Wet Grinding

(Cottell) process a composite score of 48 out of a possible 60. The ultrasonic process was the weakest in two areas which were: (1) that over a long period of time the stability of the mixture would change requiring reagitation of the mixture, and (2) that as were all the technologies addressed, the process did not meet environmental pollution limits unless expensive pollution control equipment was utilized (18:16). This process was ideal in two areas: the amount of energy required to produce the coal-oil mixture was among the least of the technologies and, secondly, no chemical additives were used in the process causing possible carcinogenic problems.

The Total Life-Cycle Cost analysis identified the ultrasonic technology as having the lowest TLCC for a twenty-five year life. Areas that put this technology ahead of the other three technologies examined were: the lower annually recurring (nonfuel) operation and maintenance costs being at $300,000 for this technology and as

high as $500,000 for the other three technologies. Also the required investment for this technology was the lowest among the alternatives analyzed. The ultrasonic process had an investment cost before adjustment of $25.0 million while the capital investment for the other technologies ran as high as $28.0 million as in the case of option number 6, the chemical additive/wet grinding technology (3:29). Another area of cost difference noted in the analysis was that the more coal used in the particular technology in proportion to No. 6 fuel oil, the lower the present value of the fuel cost would be. There is a trade-off, however, between the amount of coal used and other factors employed in the standard questionnaire such as increased air pollution and ash problems in the system with increased percentages of COM mix.

By using the two methodologies, an accurate choice within the limits of the methodology was made for the selection of the coal-oil mixture technology most suited for application at USAF installations. The selection of the ultrasonic process agrees with the contention among manufacturers that this process is most ideally suited for large commercial size boilers at the present time (19:22).

Recommendations

Based on the results of this thesis effort, the ultrasonic (Cottell) stabilization technology should be

selected as the method for retrofitting the United States Air Force's central plant boilers from No. 6 fuel-oil to coal-oil mixtures as the primary fuel.

Recommendation for Further Research

Sufficient data to employ statistical techniques in the analysis were not available. As more data becomes available on the subject of coal-oil mixtures, it is recommended that further research based on comparative statistical techniques be performed to confirm the results of this study.

APPENDICES

APPENDIX A

COAL-OIL MIXTURE CASES SURVEYED

Case Number 1

Note: The symbology 50/40/10 used in this appendix denotes percent by volume of oil/coal/and water.

Title: Full Scale Tests Firing, Coal-Oil Mixtures in a 400 MW Steam Generator.

Technology: Ultrafine Stabilization.

Performed by: A. D. Schmidt of the Florida Power & Light Company and J. L. Friedrich of the Foster Wheeler Energy Corporation.

Overview: The Florida Power & Light Company began burning a COM in its 400 MW Sanford Unit #4 steam generator on April 20, 1980. This was the first COM burned in a utility power plant which had been originally designed to burn oil. Initial coal-oil mixture tests began in May 1980 with a 20 percent/80 percent coal-oil mixture. Step increases of coal concentration were made and by September 10, 1980, a 50/50 mixture was fired.

Answers to the Survey Questions

1. Except for minor problems such as installation of furnace wall blowers to handle furnace ash removal and problems with flyash removal from the dust collector, the test was effective in meeting its objective of substituting a 50/50 coal-oil mix for No. 6 fuel oil. This technology was assigned an effective rating of 4 in this area.

2. Due to the problems associated with flyash, the retrofit was judged to be only marginally effective compared to the other technologies and was assigned a rating of 3.

3. During testing the COM began to separate and break down after passing through the oil heater enroute to the burner. This caused solid materials to separate throughout the burner supply system and become entrained which resulted in a non-uniform mix at the boiler. This technology was slightly ineffective in this area and was assigned a rating of 2.

4. Although an oil heater enroute to the boiler was employed in the system, the ultrafine technology required the lowest pre-heat temperatures of the technologies analyzed. Safety problems were minimal and the case was deemed to be extremely effective in this area being assigned a score of 5.

5. In comparing the efficiencies of coal-oil mixtures versus 100 percent No. 6 fuel oil, two factors

influenced the decrease of efficiency for the coal-oil mixtures; the increased amount of air required for coal-oil mixtures increased dry gas losses and the large combustible loss compared to 100 percent oil. The combustible losses were in the form of ash. The combustible loss for 100 percent oil is negligible. COM efficiency was from 0.7 to 1.5 percent lower than 100 percent oil. This technology was judged effective in this area and was assigned a rating of 4.

5. Referring to question number 4, the COM efficiency was only 0.7 to 1.5 percent lower than 100 percent oil. This technology was extremely effective and received a rating of 5.

6. Energy to produce the mix was small and consisted of the energy required to grind the coal into ultra-fine particles and mix it in oil. This technology was extremely effective in this area (5).

7. Chemical stabilization was not employed in this technology. This technology was assigned a rating of 5 in this area.

8. Keeping the coal in suspension was the most critical in this case out of the four analyzed. This technology without constant agitation is ineffective in this area, being assigned a rating of 1.

9. The equipment to be utilized in this retrofit was reliable and was judged to be effective by the researcher. A rating of 4 was assigned.

10. In this technology, water is not employed as an additive. This case was extremely effective in this area. A rating of 5 was assigned by the researcher as it was not required in the process.

11. As in all COM technologies, the control of pollution resulting from burning the mixture is only marginally effective. NO_x increases with increased coal concentration in the mixtures. The technology was assigned a marginally effective 3 rating in this area.

12. All the coal-oil mixture technologies can be employed as marine diesel fuel with minor modifications. The researcher assigned a value of 4 (effective) in this area.

Note: In reference to survey question 12, seasonal temperature variations will cause an uneven demand for the COM. Having alternate markets for the coal-oil mixture will prevent the possibility of plant shutdown or scale-down during the summer months.

Case Number 2

Title: Coal/Oil/Water Mixture Stability.

Technology: Ultrasonic Mixing Method.

Performed by: R. H. Carty (Process Development Division) and T. T. Coburn (Applied Science Technology Division) of the Institute for Mining and Minerals Research.

Overview: The report presented the results of a coal-oil mixture prepared by the ultrasonic stabilization method. Tests gave no indication of separation of the mixture during a six-month period. Chemical analysis of the mixture and the ash as well as the ash size distribution were determined and the results presented.

Answers to the Survey Questions

1. This mix in almost every respect was judged by the researcher to be an excellent substitute for No. 6 fuel oil. Again, except for ash problems, the technology was extremely effective. The researcher assigned a rating of 4 (effective) to this technology.

2. Out of the four technologies, this stabilization method was the easiest to employ as a retrofit project. The researcher judged this technology to be effective (5 rating) in this area.

3. Out of the four technologies analyzed, particles stayed in suspension the longest with this technology (over six months). No stabilization problems were encountered in the testing. The researcher judged this technology to be effective in this area. A rating of 4 was assigned.

4. The ultrasonic stabilization process of the technologies analyzed, required the highest temperatures in the process. But at all times adequate precautions were taken to ensure the safety of plant personnel. The researcher judged this technology to be effective in this area and assigned a rating of 4 for the ultrasonic technology.

5. As in the ultrafine process, for a 50/50 coal-oil mixture, the combustion efficiency varied from 0.7 to 1.5 percent lower than that of 100 percent oil. The

researcher judged the technology to be effective in this area and assigned a value of 4.

6. Small amounts of energy in comparison to the other technologies is required to produce the coal-oil mixture. An extremely effective rating of 5 was assigned by the researcher for the technology in this area.

7, Chemical stabilization was not employed in this technology. The researcher assigned an extremely effective rating of 5 for possible carcinogenic poisons from chemical additives as they were not used in the process at all.

8. The mixture had to be constantly agitated requiring mechanical mixers. This technology was judged by the researcher to be only marginally effective in this area. A rating of 3 was assigned.

9. The process retrofit equipment was reliable in this technology due to its relative simplicity. The rating assigned was effective--4.

10. Water as an additive was employed and due to slightly higher temperatures than employed by the ultrafine method, the water tended to convert to steam. The researcher assigned a rating of 4--effective in this area.

11. All technologies are only marginally effective in this area, receiving a rating of 3. Unless precautions are taken in pollution, there will be a problem.

12. All technologies were judged by the researcher to be effective as possible marine diesel fuels and were assigned ratings of 4.

Case Number 3

Title: The Use of Additives to Stabilize Coal-Oil Mixtures.

Technology: Chemical Additive/Dry Grinding.

Performed by: Akihiro Naka, Dai-Ichi, Kogyo Seiyaku Company, Ltd., Japan (EPDC).

Abstract: The Electric Power Development Company (EPDC) in 1979 started R&D activities on coal-oil mixtures. The Dai-Ichi Kogyo Seiyaku Company, Ltd. started research on chemical additives to stabilize the coal-oil mixture. The effectiveness of the stabilizer was tested under various conditions, i.e., vibration, heat, freezing and agitation.

Answers to the Survey Questions

1. In this case Dai-Ichi Kogyo Seiyaku Company selected an additive called ACOM (Excellent Additive for COM) and use of this chemical permitted the test to be successful in their pilot plant in Japan. As were all the technologies examined, this case received an effective rating of 4.

2. Compared to the other technologies, this case indicated that the retrofit would be slightly more difficult than the ultrasonic method, but similar to the other three technologies due to precision metering equipment required to monitor the process and chemical.

3. The purpose of the ACOM chemical additive was to provide a surfactant which would be absorbed into the coal particles. This was supposed to form a strong absorption layer which would prevent agglomeration of the coal particles. Unfortunately, ACOM was only marginally effective in providing a storable mixture. The researcher determined that the technology was only marginally effective in this area, receiving a rating of 3.

4. In this case, heat problems were not identified as a problem but from other readings on similar cases it can pose a problem for this type of technology. The researcher assigned an effective rating of 4 for this case.

5. The combustion efficiency of the ACOM additive coal-oil mixture was within the range of .7 to 1.5 percent lower than 100 percent oil, being at .79 percent. This technology received an effective rating of 4 as did the other cases falling within this range.

6. This technology used little energy in preparation of the mix. Energy that was used was employed in the mixing process itself. The researcher assigned the technology an extremely effective rating of 5 in this area.

7. Carcinogens were a minor problem in this technology utilizing a chemical additive. The Japanese researchers countered this problem by the use of baghouses and filters. The researcher assigned an effective rating of 4 for the technology in this area.

8. The ACOM additive was effective in stabilizing the coal-oil mixture over time. However, if storage was required past sixty days, restabilization by mechanical agitation was required. The researcher assigned a marginally effective rating of 3 to this technology in regards to this question.

9. The equipment required constant calibration due to the precise metering requirements of the process. The researcher assigned the technology a marginally effective rating of 3 in regard to this question.

10. In this case, the water is used primarily as a control of the flame temperature. Controlling the flame

temperature resulted in better combustion and lower particle emissions such as SO_x and NO_x. The researcher assigned an effective rating of 4 for the technology in this area.

11. Unless precise control of the entire process was maintained pollution was a problem. The researcher assigned a marginally effective rating of 3 for this technology.

12. This mixture with minor modification to the marine diesel engine, was effective as a marine diesel fuel. The researcher assigned an effective rating of 4 for this technology.

Case Number 4

Title: Fine COM Preparation Test.

Technology: Chemical Additive/ Wet Grinding.

Performed by: Masazumi Yanase, Hitachi Shipbuilding & Engineering Company, Ltd, Japan.

Abstract: This chemical additive/wet grinding test was being carried out by the Electric Power Development Company with the participation of five leading plant manufacturers: Mitsubishi Heavy Industries, Ishikawajima Harima Heavy Industries, Hitachi Kawasaki Heavy Industries and Hitachi Shipbuilding & Engineeri..g--in addition to additive makers.

A part of the project was a pilot plant test which lasted from February, 1978 to April, 1979. In general, the pilot plant test of the mixture was successful.

Answers to the Survey Questions

1. This test by the Japanese companies showed that substituting a chemical additive/wet grinding coal-oil mixture for No. 6 fuel-oil is feasible. The researcher assigned an effective rating of 4 for this technology.

2. Compared to the other technologies, this case indicated that the retrofit would be slightly more difficult than the ultrasonic method but similar to the other three technologies due to precision metering equipment required to monitor the process.

3. The purpose of the chemical additive was to provide a surfactant which would be absorbed into the coal particles. This was supposed to form a strong absorption layer which would prevent agglomeration of the particles. As was the chemical additive/dry grinding method, the test was only able to show marginal effectiveness in providing a storable mixture. The researcher assigned this technology a rating of 3.

4. In this case, heat problems were not identified as a problem but from other readings on similar cases it can pose a problem for this and other chemical additive technology. The researcher assigned an effective rating of 4 for this technology.

5. At 1.0 percent lower than 100 percent No. 6 fuel-oil, this technology fell within the effective range and was assigned a rating of 4.

5. In the wet grinding/chemical additive method slightly more energy is required to produce the mix. Exact figures were not given, but the case did indicate it required more than the other technologies. The researcher assigned an effective rating of 4.

7. Carcinogens were a minor problem in this technology using a chemical additive. As in the other chemical additive technology, the researcher assigned an effective rating of 4.

8. Similar to the previous chemical additive technology, the mix would not stay in suspension past sixty days. The researcher assigned a marginally effective rating of 3.

9. Due to precision monitoring equipment required, this technology was only marginally effective in this area. receiving a rating of 3.

10. Water posed erosion problems more severe than in any of the other technologies. This technology is only marginally effective in this area, being rated 3.

11. Again, unless precise control of the process was maintained, pollution became a problem. The researcher assigned a marginally effective rating of 3.

12. As were all the coal-oil mixture technologies, with minor modification to the marine diesel engine, this coal-oil mixture is effective (4) as a marine engine fuel.

APPENDIX B

SURVEY INSTRUMENT WITH RATING KEY

The Standard Questionnaire

1. How successful was the case in meeting its objective of substituting a coal-oil mixture for No. 6 fuel oil as the boiler's primary fuel?

2. In comparison to other coal-oil mixture technologies, how difficult would the retrofit be?

3. Would storage of the coal-oil mixture pose a problem due to settlement of coal particles?

4. To produce the coal-oil mixture and then burn it in the boiler plant, would high temperatures in the process cause safety problems for the plant personnel?

5. How does the combustion efficiency of the coal-oil mixture compare to No. 6 fuel oil?

6. Would excessive energy be used to produce the coal-oil mixture?

7. If chemical stabilization is employed in the coal-oil mixture, will the additive cause environmental problems in the form of carcinogens?

8. Will the stability of the mixture change over time requiring restabilization?

9. How reliable at the present time is the equipment to be used in preparing and burning the coal-oil mixture?

10. In technologies that use water as an additive, does the water work as predicted or does it cause additional problems in the process?

11. How well does the retrofit meet environmental air pollution standards?

12. Can the coal-oil mixture be employed as another fuel such as marine diesel fuel?

Note: All questions were given a rating of from 1 to 5. A key to the ratings follows.

Key to Ratings for the Subjective Questionnaire

Rating	Description of the Rating
5	extremely effective--boiler plants using the given stabilization process met or exceeded the requirements of the particular question.
4	effective--boiler plants using the given stabilization process met the requirements of the question but problems were noted.
3	marginally effective--boiler plants using the given stabilization process were not able to ascertain if the process was effective or not.
2	slightly ineffective--in boiler plants using the given stabilization process, the requirements of the particular question were not met.
1	ineffective--in boiler plants using the given stabilization process, none of the requirements of the question were met.

APPENDIX C

LIFE-CYCLE COST ANALYSIS WORKSHEETS

Introduction

Data used in the Total Life-Cycle Cost analysis were obtained from an economic report published by the Davy McKee Corporation titled "Coal-Oil Mixture Economics, October 1979" and from a report titled "A Comparative Study of COM Preparation Technologies" accomplished by J. K. O'Neill, reference 17.

Data for energy costs was obtained through interviews with Mr. David C. Fuller of CoaLiquid, Inc., reference 9.

OPTION #1--Existing No. 6 Fuel-Oil Boiler Plant

ECONOMIC ANALYSIS OF A RETROFIT PROJECT

MAJOR COMMAND: ____________________

BASE: ____________________

PROJECT OFFICER: Captain Edward J. Pokora

POSITION: Graduate Student

TELEPHONE: AUTOVON: ____________________

COMMERCIAL: ____________________

BUILDING OR FACILITY DESCRIPTION: A boiler capable of burning 5000 barrels of No. 6 fuel oil per day.

BUILDING NUMBER: ____________________

CLASSIFICATION: RESIDENTIAL: ____________________

COMMERCIAL: ____________________

INDUSTRIAL: X

STUDY PERIOD: FROM 1980 TO 2005

Not to exceed 25 years.

PROGRAMMED AMOUNT: OPTION 1: ____________

OPTION 2: ____________

OPTION 3: ____________

OPTION 4: ____________

OPTION 5: ____________

A. Calculating the Present Value of Energy Costs Without the Retrofit

TYPE	ANNUAL UNITS OF ENERGY PURCHASED	BASE-YEAR ENERGY PRICE PER UNIT	BASE-YEAR ENERGY COSTS	UPW* FACTOR	PRESENT VALUE OF ENERGY COSTS
Electricity	______	______	\$______ Base Charge	______	\$______
			\$______ Demand Charge		\$______
			\$______ Time of Day Charge		\$______
			\$______ Contract Capacity Charge		\$______
		From Table C-1 (5:138)	\$______ Other Charge Component	From Table B-1	\$______
OIL No. 6	\$9,702,000 mmbtu/yr	\$6.93/mmbru	\$67.2 x 10^6	16.95	\$1,139.6 x 10^6
GAS					
OTHER____					
TOTAL					

B. Calculating Investment Costs for the Existing System Without the Retrofit

(1) Base-Year resale, salvage, or reuse value of any existing system that must be replaced for continued use of the facility. \$ 0

(2) Base-Year renovation costs for the existing system if the retrofit project is not implemented. \$ 0

(3) Total of investment costs: (2) - (1) \$ 0

C. Calculating Annually Recurring Nonfuel Operation and Maintenance (O&M) Costs Without the Retrofit

Amount of Annually Recurring Costs in Base Year	UPW Factor	Present Value of Annually Recurring Costs
$ $625,000	11.65 Table B-1	$ 7,281,250

Primarily the difference in personnel costs.

D. Calculating Non-Annually Recurring O&M (Non-Fuel) Costs, Replacement Costs, and Salvage Value Without the Retrofit

Year in Which Expenditure Is Expected To Occur	Amount of Non-Annually Recurring O&M Costs (In Base-Year $)[1]	Amount of Replacement Costs (In Base-Year $)	Amount of Salvage Value (In Base-Year $)	SPW Factors	Present Value of Non-Annually Recurring O&M Costs	Present Value of Replacement	Present Value of Salvage Value
TOTAL					0	0	0

E. Calculating TLCC Without The Retrofit

(1)	Present Value of Energy Costs	$ $1,139.6 \times 10^6$
(2)	Present Value of Investment Costs	$ 0
(3)	Present Value of Annually Recurring (Nonfuel) O&M Costs	$ 7.281×10^6
(4)	Present Value of Nonannually Recurring (Nonfuel) O&M Costs	$ 0
(5)	Present Value of Replacement Costs	$ 0
(6)	Present Value of Salvage	$ 0
(7)	TLCC Without the Retrofit: (1)+(2)+(3)+(4)+(5)-(6)	$ $1,146.9 \times 10^6$

OPTION #2--From 100 percent Oil-Fired to 100 Percent Coal-Fired

Parts F Through J Calculate TLCC with the Retrofit

F. Calculating the Present Value of Fuel Costs With the Retrofit

TYPE	ANNUAL UNITS OF ENERGY PURCHASED	ENERGY PRICE PER UNIT	BASE-YEAR ENERGY COSTS	UPW* FACTOR	PRESENT VALUE OF ENERGY COSTS
Electricity	______	______	$______ Base Charge	______	$______
			$______ Demand Charge		$______
			$______ Time of Day Charge		$______
			$______ Contract Capacity Charge		$______
			$______ Other Charge Component		$______
OIL					
GAS					
OTHER COAL	9,702,000 mmbtu/yr	$1.46/mmbtu	$14.16 x 10^6	16.48	$233.3 x 10^6
TOTAL					$233.3 x 10^6

G. Calculating Investment Costs with the Retrofit

		Figure obtained from Reference 3
(1)	Estimated Actual Investment Costs for the Retrofit Project	$ 27,000,000
(2)	Investment Cost Adjustment Factor	$ .9
(3)	Adjusted Investment Costs for the Retrofit Project (1)x(2)	$ 24,300,000
(4)	Base-Year Renovation Costs for the Existing System if the Retrofit Project is Implemented	$ 0
(5)	Total Adjusted Present Value Investment Costs Attributable to the Retrofit Project (3)+(4)	$ 24,300,000

OPTION NO. ___, Page 1

H. Calculating Annually Recurring (Nonfuel) Operation and Maintenance (O&M) Costs With the Retrofit

Amount of Annually Recurring Costs in Base Year	UPW Factor	Present Value of Annually Recurring Costs
$ 0	-	$ 0

I. Calculating Nonannually Recurring (Nonfuel) O&M Costs, Replacement Costs, and Salvage Value With the Retrofit

Year In Which Expenditure Is Expected To Occur	Amount of Non-Annually Recurring O&M Costs (In Base-Year $)	Amount of Replacement Costs (In Base-Year $)	Amount of Salvage Value (In Base-Year $)	SPW Factors	Present Value of Non-Annually Recurring O&M Costs	Present Value of Replacement	Present Value of Salvage Value
TOTAL					0	0	0

J. Calculating TLCC With the Retrofit Project

(1) Present Value of Energy Costs	$\$233.6 \times 10^6$
(2) Present Value of Adjusted Investment Costs	24.3×10^6
(3) Present Value of Annually Recurring (Nonfuel) O&M Costs	0
(4) Present Value of Nonannually Recurring (Nonfuel) O&M Costs	0
(5) Present Value of Replacement Costs	0
(6) Present Value of Salvage	0
(7) TLCC With the Retrofit Project (1)+(2)+(3)+(4)+(5)-(6)	$\$257.9 \times 10^6$

K. SIR Calculation

(1) SIR Numerator	
(a) Energy Costs Savings from the Retrofit, $(E_e - E_r)$	$\$ 881.7 \times 10^6$
(b) Change in Nonfuel O&M Costs, $(M_e - M_r)$	\$ 0
(c) SIR Numerator, (a)+(b)	$\$ 881.7 \times 10^6$
(2) SIR Denominator	
(a) Adjusted Differential Investment Cost, $(I_r - I_e)$	$\$ 24.3 \times 10^6$
(b) Change in Replacement Costs, $(R_r - R_e)$	\$ 0
(c) Change in Salvage Value, $(S_r - S_e)$	\$ 0
(d) SIR Denominator, (a)+(b)-(c)	$\$ 24.3 \times 10^6$
(3) SIR for Ranking the Retrofit Project	29.4

OPTION #3—From Oil-Fired to Ultrafine Grinding COM

Parts F Through J Calculate TLCC with the Retrofit

F. Calculating the Present Value of Fuel Costs With the Retrofit

TYPE	ANNUAL UNITS OF ENERGY PURCHASED	ENERGY PRICE PER UNIT	BASE-YEAR ENERGY COSTS	UPW* FACTOR	PRESENT VALUE OF ENERGY COSTS
Electricity	____	____	$____ Base Charge	____	$____
			$____ Demand Charge		$____
			$____ Time of Day Charge		$____
			$____ Contract Capacity Charge		$____
	50/50 Coal-Oil Mix		$____ Other Charge Component		$____ Table 3-1
OIL No. 6	4,851,000 mmbtu/yr	$6.93/mmbtu	$33.6 x 10^6	19.95	$569.8 x 10^6
GAS					
OTHER COAL	4,851,100 mmbtu/yr	$1.46/mmbtu	$7.08 x 10^6	16.48	$116.7 x 10^6
TOTAL					$686.5 x 10^6

G. Calculating Investment Costs with the Retrofit

(1)	Estimated Actual Investment Costs for the Retrofit Project	$25.0 x 10^6
(2)	Investment Cost Adjustment Factor	$ .9
(3)	Adjusted Investment Costs for the Retrofit Project (1)x(2)	$22.5 x 10^6
(4)	Base-Year Renovation Costs for the Existing System if the Retrofit Project is Implemented	$ 0
(5)	Total Adjusted Present Value Investment Costs Attributable to the Retrofit Project (3)+(4)	$22.5 x 10^6

H. Calculating Annually Recurring (Nonfuel) Operation and Maintenance (O&M) Costs With the Retrofit

Amount of Annually Recurring Costs in Base Year	UPW Factor	Present Value of Annually Recurring Costs
$ $500,000	11.65	$ 5,825,000

Table A-1

I. Calculating Nonannually Recurring (Nonfuel) O&M Costs, Replacement Costs, and Salvage Value With the Retrofit

Year In Which Expenditure Is Expected To Occur	Amount of Non-Annually Recurring O&M Costs (In Base-Year $)	Amount of Replacement Costs (In Base-Year $)	Amount of Salvage Value (In Base-Year $)	SPW Factors	Present Value of Non-Annually Recurring O&M Costs	Present Value of Replacement	Present Value of Salvage Value
5	$50,000			0.71	$35,500		
10	$50,000	$200,000		0.51	$25,500	$102,000	
15	$50,000			0.36	$18,000		
20	$50,000			0.26	$13,000		
TOTAL					$92,000	$102,000	0

J. Calculating TLCC With the Retrofit Project

(1)	Present Value of Energy Costs	$\$686.0 \times 10^6$
(2)	Present Value of Adjusted Investment Costs	22.5×10^6
(3)	Present Value of Annually Recurring (Nonfuel) O&M Costs	5.825×10^6
(4)	Present Value of Nonannually Recurring (Nonfuel) O&M Costs	$.092 \times 10^6$
(5)	Present Value of Replacement Costs	$.102 \times 10^6$
(6)	Present Value of Salvage	0
(7)	TLCC With the Retrofit Project (1)+(2)+(3)+(4)+(5)-(6)	$\$714.5 \times 10^6$

K. SIR Calculation

(1)	SIR Numerator	
(a)	Energy Costs Savings from the Retrofit, (E_e-E_r)	$\$\ 425.08 \times 10^6$
(b)	Change in Nonfuel O&M Costs, (M_e-M_r)	$\$\ -5.825 \times 10^6$
(c)	SIR Numerator, (a)+(b)	$\$\ 419.3 \times 10^6$
(2)	SIR Denominator	
(a)	Adjusted Differential Investment Cost, (I_r-I_e)	$\$\ 22.5 \times 10^6$
(b)	Change in Replacement Costs, (R_r-R_e)	$\$\ .102 \times 10^6$
(c)	Change in Salvage Value, (S_r-S_e)	$\$\ 0$
(d)	SIR Denominator, (a)+(b)-(c)	$\$\ 22.6 \times 10^6$
(3)	SIR for Ranking the Retrofit Project	18.6

OPTION #4--From Oil-Fired to an Ultrasonic COM

Parts F Through J Calculate TLCC with the Retrofit

F. Calculating the Present Value of Fuel Costs With the Retrofit

TYPE	ANNUAL UNITS OF ENERGY PURCHASED	ENERGY PRICE PER UNIT	BASE-YEAR ENERGY COSTS	UPW* FACTOR	PRESENT VALUE OF ENERGY COSTS
Electricity	______	______	$______ Base Charge $______ Demand Charge $______ Time of Day Charge $______ Contract Capacity Charge $______ Other Charge Component	______	$______ $______ $______ $______ $______
50/40/10--Coal-Oil Water Mix					
OIL No. 6	4,851,000 mmbtu/yr	$6.93/mmbtu	$33.6 x 10^6	16.95	$659.8 x 10^6
GAS Water	Cost assumed to be	insignificant.			
OTHER ~~Coal~~	3,880,800 mmbtu/yr	$1.46/mmbtu	$5.665 x 10^6	16.48	93.34 x 10^6
TOTAL					$663.14 x 10^6

G. Calculating Investment Costs with the Retrofit

(1) Estimated Actual Investment Costs for the Retrofit Project $ 23.0 x 10^6

(2) Investment Cost Adjustment Factor $ 0

(3) Adjusted Investment Costs for the Retrofit Project (1)x(2) $ 20.7 x 10^6

(4) Base-Year Renovation Costs for the Existing System if the Retrofit Project is Implemented $ 0

(5) Total Adjusted Present Value Investment Costs Attributable to the Retrofit Project (3)+(4) $ 20.7 x 10^6

H. Calculating Annually Recurring (Nonfuel) Operation and Maintenance (O&M) Costs With the Retrofit

Amount of Annually Recurring Costs in Base Year	UPW Factor	Present Value of Annually Recurring Costs
$ 300,000	11.65	$ 3,495,000

I. Calculating Nonannually Recurring (Nonfuel) O&M Costs, Replacement Costs, and Salvage Value With the Retrofit

Year In Which Expenditure Is Expected To Occur	Amount of Non-Annually Recurring O&M Costs (In Base-Year $)	Amount of Replacement Costs (In Base-Year $)	Amount of Salvage Value (In Base-Year $)	SPW Factors	Present Value of Non-Annually Recurring O&M Costs	Present Value of Replacement	Present Value of Salvage Value
5	$25,000			0.71	$17,750		
10	$25,000	$200,000		0.51	$12,750	$102,000	
15	$25,000			0.36	$ 9,000		
20	$25,000			0.26	$ 6,500		
	CoaLiquid, Inc. says use 50% less than ultrafine						
TOTAL					$46,000	$102,000	0

J. Calculating TLCC With the Retrofit Project

(1)	Present Value of Energy Costs	$\$663.1 \times 10^6$
(2)	Present Value of Adjusted Investment Costs	20.7×10^6
(3)	Present Value of Annually Recurring (Nonfuel) O&M Costs	3.495×10^6
(4)	Present Value of Nonannually Recurring (Nonfuel) O&M Costs	$.046 \times 10^6$
(5)	Present Value of Replacement Costs	$.102 \times 10^6$
(6)	Present Value of Salvage	0
(7)	TLCC With the Retrofit Project (1)+(2)+(3)+(4)+(5)-(6)	$\$687.48 \times 10^6$

K. SIR Calculation

(1) SIR Numerator

(a)	Energy Costs Savings from the Retrofit, $(E_e - E_r)$	$ 452.1×10^6
(b)	Change in Nonfuel O&M Costs, $(M_e - M_r)$	$ -3.495×10^6
(c)	SIR Numerator, (a)+(b)	$ 448.6×10^6

(2) SIR Denominator

(a)	Adjusted Differential Investment Cost, $(I_r - I_e)$	$ 20.7×10^6
(b)	Change in Replacement Costs, $(R_r - R_e)$	$ $.102 \times 10^6$
(c)	Change in Salvage Value, $(S_r - S_e)$	$ 0
(d)	SIR Denominator, (a)+(b)-(c)	$ 20.802×10^6

(3) SIR for Ranking the Retrofit Project 21.6

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OPTION #5--From Oil-Fired to Chemical Additive/Dry Grinding COM

Parts F Through J Calculate TLCC with the Retrofit

F. Calculating the Present Value of Fuel Costs With the Retrofit

TYPE	ANNUAL UNITS OF ENERGY PURCHASED	ENERGY PRICE PER UNIT	BASE-YEAR ENERGY COSTS	UPW* FACTOR	PRESENT VALUE OF ENERGY COSTS
Electricity	______	______	$______ Base Charge	______	$______
			$______ Demand Charge		$______
			$______ Time of Day Charge		$______
			$______ Contract Capacity Charge		$______
50/50 mix coal/oil with chemical			$______ Other Charge Component		$______
OIL No. 6	4,851,000 mmbtu/yr	$6.93/mmbtu	$33.6 x 10^6	16.95	$569.8 x 10^6
GAS Chemical	9,702,000 mmbtu/yr	$ .05/mmbtu	$.485 x 10^6	16.81	$8.15 x 10^6
OTHER Coal	4,851,000 mmbtu/yr	$1.46/mmbtu	$7.08 x 10^6	16.48	$116.7 x 10^6
TOTAL					$694.65 x 10^6

Distillate Figure

G. Calculating Investment Costs with the Retrofit

(1) Estimated Actual Investment Costs for the Retrofit Project $ 27.0 x 10^6

(2) Investment Cost Adjustment Factor $ .9

(3) Adjusted Investment Costs for the Retrofit Project (1)x(2) $ 24.3 x 10^6

(4) Base-Year Renovation Costs for the Existing System if the Retrofit Project is Implemented $ 0

(5) Total Adjusted Present Value Investment Costs Attributable to the Retrofit Project (3)+(4) $ 24.3 x 10^6

H. Calculating Annually Recurring (Nonfuel) Operation and Maintenance (O&M) Costs With the Retrofit

Amount of Annually Recurring Costs in Base Year	UPW Factor	Present Value of Annually Recurring Costs
$ 500,000	11.65	$ 5,825,000

I. Calculating Nonannually Recurring (Nonfuel) O&M Costs, Replacement Costs, and Salvage Value With the Retrofit

Year In Which Expenditure Is Expected To Occur	Amount of Non-Annually Recurring O&M Costs (In Base-Year $)	Amount of Replacement Costs (In Base-Year $)	Amount of Salvage Value (In Base-Year $)	SPW Factors	Present Value of Non-Annually Recurring O&M Costs	Present Value of Replacement	Present Value of Salvage Value
5	$60,000			0.71	$42,600		
10	$60,000	$250,000		0.51	$30,600	$127,500	
15	$60,000			0.36	$21,600		
20	$60,000			0.26	$15,600		
TOTAL					$110,400	$127,500	0

J. Calculating TLCC With the Retrofit Project

(1)	Present Value of Energy Costs	$\$694.65 \times 10^6$
(2)	Present Value of Adjusted Investment Costs	24.3×10^6
(3)	Present Value of Annually Recurring (Nonfuel) O&M Costs	5.825×10^6
(4)	Present Value of Nonannually Recurring (Nonfuel) O&M Costs	$.1104 \times 10^6$
(5)	Present Value of Replacement Costs	$.1275 \times 10^6$
(6)	Present Value of Salvage	0
(7)	TLCC With the Retrofit Project (1)+(2)+(3)+(4)+(5)-(6)	$\$725.01 \times 10^6$

K. SIR Calculation

(1) SIR Numerator

(a)	Energy Costs Savings from the Retrofit, $(E_e - E_r)$	$\$\ 414.6 \times 10^6$
(b)	Change in Nonfuel O&M Costs, $(M_e - M_r)$	$\$\ -5.825 \times 10^6$
(c)	SIR Numerator, (a)+(b)	$\$\ 408.8 \times 10^6$

(2) SIR Denominator

(a)	Adjusted Differential Investment Cost, $(I_r - I_e)$	$\$\ 24.3 \times 10^6$
(b)	Change in Replacement Costs, $(R_r - R_e)$	$\$\ .1275 \times 10^6$
(c)	Change in Salvage Value, $(S_r - S_e)$	\$ 0
(d)	SIR Denominator, (a)+(b)-(c)	$\$\ .24.43 \times 10^6$

(3) SIR for Ranking the Retrofit Project 16.7

OPTION #6--From Oil-Fired to Chemical Additive/Wet Grinding COM

Parts F Through J Calculate TLCC with the Retrofit

F. Calculating the Present Value of Fuel Costs With the Retrofit

TYPE	ANNUAL UNITS OF ENERGY PURCHASED	ENERGY PRICE PER UNIT	BASE-YEAR ENERGY COSTS	UPW* FACTOR	PRESENT VALUE OF ENERGY COSTS
Electricity	________	________	$________ Base Charge	____	$________
			$________ Demand Charge		$________
			$________ Time of Day Charge		$________
			$________ Contract Capacity Charge		$________
			$________ Other Charge Component		$________
50/50 Coal/Oil Mix with Chemical Additive					
OIL No. 6	4,851,000 mmbtu/yr	$6.93/mmbtu	$33.6 x 10^6	16.95	$569.8 x 10^6
GAS Chemical	9,702,000 mmbtu/yr	$ .10/mmbtu	$.970 x 10^6	16.81	$16.31 x 10^6
OTHER Coal	4,851,000 mmbtu/yr	$1.46/mmbtu	$7.08 x 10^6	16.48	$116.7 x 10^6
TOTAL					$702.81 x 10^6

G. Calculating Investment Costs with the Retrofit

(1)	Estimated Actual Investment Costs for the Retrofit Project	$ 28.0 x 10^6
(2)	Investment Cost Adjustment Factor	$ .9
(3)	Adjusted Investment Costs for the Retrofit Project (1)x(2)	$ 25.2 x 10^6
(4)	Base-Year Renovation Costs for the Existing System if the Retrofit Project is Implemented	$ 0
(5)	Total Adjusted Present Value Investment Costs Attributable to the Retrofit Project (3)+(4)	$ 25.2 x 10^6

H. Calculating Annually Recurring (Nonfuel) Operation and Maintenance (O&M) Costs With the Retrofit

Amount of Annually Recurring Costs in Base Year	UPW Factor	Present Value of Annually Recurring Costs
$ 500,000	11.65	$ 5,825,000

I. Calculating Nonannually Recurring (Nonfuel) O&M Costs, Replacement Costs, and Salvage Value With the Retrofit

Year In Which Expenditure Is Expected To Occur	Amount of Non-Annually Recurring O&M Costs (In Base-Year $)	Amount of Replacement Costs (In Base-Year $)	Amount of Salvage Value (In Base-Year $)	SPW Factors	Present Value of Non-Annually Recurring O&M Costs	Present Value of Replacement	Present Value of Salvage Value
5	$60,000			0.71	$42,600		
10	$60,000	$290,000		0.51	$30,600	$147,900	
15	$60,000			0.36	$21,600		
20	$60,000			0.26	$15,600		
TOTAL					$110,400	$147,900	0

J. Calculating TLCC With the Retrofit Project

(1)	Present Value of Energy Costs	$\$702.8 \times 10^6$
(2)	Present Value of Adjusted Investment Costs	25.2×10^6
(3)	Present Value of Annually Recurring (Nonfuel) O&M Costs	5.825×10^6
(4)	Present Value of Nonannually Recurring (Nonfuel) O&M Costs	$.1104 \times 10^6$
(5)	Present Value of Replacement Costs	$.1479 \times 10^6$
(6)	Present Value of Salvage	0
(7)	TLCC With the Retrofit Project (1)+(2)+(3)+(4)+(5)-(6)	$\$734.1 \times 10^6$

K. SIR Calculation

(1) SIR Numerator

(a)	Energy Costs Savings from the Retrofit, (E_e-E_r)	$\$405.5 \times 10^6$
(b)	Change in Nonfuel O&M Costs, (M_e-M_r)	$\$-5.825 \times 10^6$
(c)	SIR Numerator, (a)+(b)	$\$399.7 \times 10^6$

(2) SIR Denominator

(a)	Adjusted Differential Investment Cost, (I_r-I_e)	$\$25.2 \times 10^6$
(b)	Change in Replacement Costs, (R_r-R_e)	$\$.1479 \times 10^6$
(c)	Change in Salvage Value, (S_r-S_e)	\$ 0
(d)	SIR Denominator, (a)+(b)-(c)	$\$25.35 \times 10^6$

(3) SIR for Ranking the Retrofit Project 15.8

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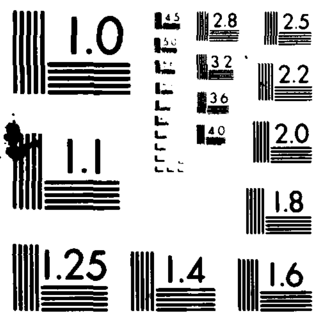

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